

# Characterization of Indoor Air Quality Using Multiple Measurements of Nitrogen Dioxide and Volatile Organic Compounds

Bu Soon Son<sup>\*\*</sup>, Won Ho Yang<sup>\*\*</sup>, Jong Ryeal Sohn<sup>\*\*\*</sup>,  
Dae Won Kim<sup>\*\*\*\*</sup>, Soon Won Jung<sup>\*</sup>, Young Hee Kim<sup>\*\*</sup>

*\*Department of Environmental Health Science, Soonchunhyang University, Asan, 336-745, Korea*

*\*\*Department of Occupational Health, Catholic University of Daegu, Daegu, 712-702, Korea*

*\*\*\*Research Center for Environmental Health, College of Health Science, Korea University, Seoul, 136-703, Korea*

*\*\*\*\*Department of Environmental Science, Catholic University of Daegu, Daegu, 712-702, Korea*

---

### Abstract

Indoor air quality can be affected by indoor sources, ventilation, decay and outdoor levels. Although technologies exist to measure these factors, direct measurements are often difficult. The purpose of this study was to develop an alternative method to characterize indoor environmental factors by multiple indoor and outdoor measurements. Indoor and outdoor NO<sub>2</sub> and VOCs (benzene, toluene, xylene) concentrations were measured every 3 days for 60 consecutive days in 30 houses in Seoul, Asan and Daegu, Korea. Using a mass balance model and regression analysis, penetration factor (ventilation rate divided by the sum of ventilation rate and deposition constant) and source strength factor (source strength divided by the sum of ventilation rate and deposition constant) were calculated using multiple indoor and outdoor measurements. Subsequently, NO<sub>2</sub> and VOCs source strengths (ppb/hr) and deposition constant (K, hr<sup>-1</sup>) were estimated. Deposition constants of NO<sub>2</sub>, toluene and xylene were  $0.98 \pm 0.28$ ,  $0.71 \pm 0.24$  and  $0.74 \pm 0.53$  hr<sup>-1</sup>, respectively. Source strengths of NO<sub>2</sub>, toluene and xylene were  $16.28 \pm 7.47$ ,  $31.25 \pm 38.45$  and  $23.45 \pm 19.67$  ppb/hr, respectively. In conclusion, indoor environmental factors were effectively characterized by this method using multiple indoor and outdoor measurements.

### Introduction

Indoor air quality is the dominant contributor to total personal exposure because most people spend a majority of their time indoors (Spengler et al., 1994). Especially when indoor environments have sources of contaminants, exposure to indoor air can potentially pose a greater threat than exposure to ambient air. Changes in construction designs and the increased use of synthetic products may result in an increasing number of complaints about the quality of indoor

air, both at home and in the workplace (Jones, 1999). Indoor air quality is affected by outdoor air pollution, indoor generation of pollutants, pollution depletion mechanisms (surface deposition and chemical decay), ventilation, and volume of the indoor space. Although technologies exist to measure these factors directly, it is not practical to directly measure all the factors in field studies.

The purposes of this study were to characterize indoor air quality using multiple NO<sub>2</sub> and VOCs (benzene, toluene, xylene) measurements, to estimate ventilation rate and NO<sub>2</sub> source strength, and to compare the indoor air quality characteristics in Brisbane, Australia to those in Seoul, Korea. The two cities have many different characteristics such as house type, weather, industry and ambient pollution levels.

## Materials and Method

To estimate the deposition constant and source strength of NO<sub>2</sub> and VOCs in indoor environments, indoor and outdoor concentrations every 3 days each 10 house in Seoul, Asan, and Daegu, Korea, were measured between August and October in 2004. In addition, information on house characteristics was collected by identical questionnaires in the three cities. All NO<sub>2</sub> (Toyo Roshi Kaisha, Ltd, Japan) and VOCs (3M OVM, 3M, USA) concentrations were measured using passive sampler (Yanagisawa and Nishimura, 1982)

A mass balance model is often used to explain indoor air quality. Indoor air quality models using mass balance are a useful tool to quantify the relationship between indoor air pollution levels, ambient concentrations, and explanatory variables (Ott et al., 1996). Models of indoor air quality describe the transport and dispersion of pollutants throughout a structure and the variation of indoor air pollutants as a function of source strengths, air change rates, removal mechanisms, and other factors. Considering a residence as a single chamber (one-compartment), a mass balance in the chamber provides,

$$\frac{dC_i}{dt} = mIC_o + S - mIC_i - \frac{R}{V} \quad (1)$$

Where, C<sub>i</sub>= indoor concentration (μg/m<sup>3</sup>), C<sub>o</sub>= outdoor concentration (μg/m<sup>3</sup>), I= ventilation rate (hr<sup>-1</sup>), S= source strength (μg/m<sup>3</sup>·hr) = emission rate (μg/hr)/volume of the space (m<sup>3</sup>), R= decay rate (μg/hr), m= mixing factor (unitless), and V= volume of the space (m<sup>3</sup>).

The removal rate, R, is a function of a deposition constant (K, hr<sup>-1</sup>) and the mass of pollutant present indoor (VC<sub>i</sub>).

$$R = KVC_i \quad (2)$$

Assuming that the indoor environment is completely mixed (m=1), equation (1) becomes.

$$\frac{dC_i}{dt} = IC_o + S - IC_i - KC_i \quad (3)$$

Assuming that indoor level is in a steady-state condition ( $dC/dt=0$ ), the equation (4) can be obtained.

$$C_{i(ss)} = \left(\frac{I}{I+K}\right)C_o + \left(\frac{S}{I+K}\right) \quad (4)$$

where,  $C_{i(ss)}$  = average steady-state indoor  $\text{NO}_2$  concentration.

Substituting  $I/(I+K)$  for A and  $S/(I+K)$  for B, rearranging terms allow the average concentration of the house to be written as a linear regression equation.

$$C_{i(ss)} = AC_o + B \quad (5)$$

Because we measured indoor and outdoor concentrations simultaneously, linear regression analysis provided A and B of equation 5. In equation 5, the penetration factor, A, should be between zero and 1. The source strength factor, B, should be greater than or equal to zero because S is greater than or equal to zero.

## Results and Discussion

A total of 30 participants were recruited in Seoul, Asan and Daegu. Measurements from three participants were excluded from the following analysis because they refused to participate after 2 weeks of measurements. The mean number of family members was 3.4 and 28 houses were apartments. None of the houses had kerosene or coal heaters.

The  $\text{NO}_2$  measurements are shown in Figure 1. Means of indoor and outdoor every 3 days  $\text{NO}_2$  concentrations in Seoul, Asan and Daegu were 32.7 ppb, 25.9 ppb and 19.7 ppb, respectively. The mean ratio of indoor to outdoor (I/O)  $\text{NO}_2$  concentrations was 0.95, 0.81 and 1.09, respectively. VOCs measurements are shown in Table 1. The indoor and outdoor VOCs concentrations measured in houses constructed before 4 years were significantly higher than those after 4 years ( $p<0.05$ ).

Penetration factor (ventilation rate divided by the sum of ventilation rate and deposition constant) and source strength factor (source strength divided by the sum of ventilation rate and deposition constant) were calculated using equation. Penetration factors were between zero and 1 except for one house in Seoul and the source strength factors were more than zero in all houses.

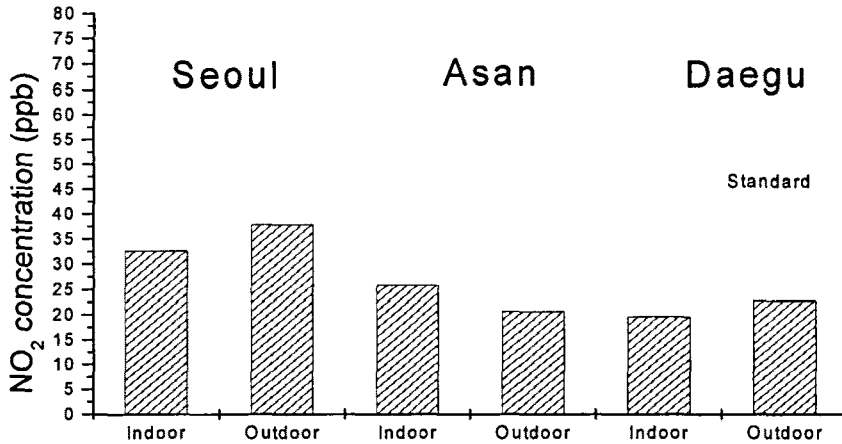


Figure 1. Measured NO<sub>2</sub> concentrations in Seoul, Asan and Daegu, Korea.

Table 1. Measured benzene, toluene and xylene concentrations in Seoul, Asan and Daegu, Korea.

		Benzene (ppb)		Toluene (ppb)		m-Xylene (ppb)		
		Average ± S.D.	Range	Average ± S.D.	Range	Average ± S.D.	Range	
Seoul (n= 9)	Before 4 year	Indoor	4.01±2.65	0.20~21.5	81.25±56.34	11.8~198.32	25.56±19.85	6.51~65.2
		Outdoor	4.02±3.21	0.21~31.5	74.3±51.69	9.34~201.5	24.35±18.45	5.32~35.2
	After 4 year	Indoor /outdoor	1.12±0.87	0.31~9.57	1.28±1.25	0.20~7.56	1.24±1.23	0.35~5.24
		Indoor	3.84±3.31	0.34~19.5	77.65±65.32	11.25~174.23	18.42±17.25	3.65~21.25
	After 4 year	Outdoor	3.99±4.56	0.41~22.6	79.85±47.69	13.25~195.63	19.99±18.56	3.89~35.2
		Indoor /outdoor	0.87±0.65	0.19~2.87	0.75±1.11	0.22~1.45	0.95±0.45	0.89±2.20
Asan (n= 9)	Before 4 year	Indoor	2.58±2.64	0.10~17.37	75.17±52.41	9.18~203.50	19.14±16.35	2.87~100.48
		Outdoor	3.93±2.65	0.16~10.17	63.02±41.55	5.73~161.68	18.64±21.05	2.76~134.48
	After 4 year	Indoor /outdoor	1.16±2.02	0.04~11.19	1.32±0.98	0.11~8.08	1.29±1.01	0.21~7.23
		Indoor	1.96±1.70	0.12~6.1	17.05±8.46	6.51~42.05	7.06±1.58	2.94~9.87
	After 4 year	Outdoor	2.61±2.20	0.11~9.83	34.88±25.35	7.73~141.95	6.51±3.07	2.82~13.9
		Indoor /outdoor	0.81±0.62	0.20~2.01	0.58±0.28	0.18~1.32	1.04±0.35	0.49~1.71
Daegu (n= 9)	Before 4 year	Indoor	4.25±3.25	0.34~22.5	80.36±65.24	10.2~174.56	19.56±17.54	3.85~99.58
		Outdoor	4.11±4.25	0.31~20.6	77.52±62.32	12.35~184.56	17.54±17.68	3.54~102.56
	After 4 year	Indoor /outdoor	1.31±2.69	0.25~4.25	1.11±1.24	0.31~5.63	1.18±1.58	0.41~4.95
		Indoor	2.65±1.99	0.12~16.5	69.25±52.36	11.85~145.2	8.65±3.56	2.51~15.2
	After 4 year	Outdoor	3.87±3.32	0.35~19.68	71.65±58.36	9.65~172.56	8.51±4.98	3.21~14.98
		Indoor /outdoor	0.78±0.68	0.21~1.58	0.52±0.86	0.09~2.31	0.97±0.42	0.88~2.84

Deposition constant can be estimated from penetration factor and source strength can be estimated from source strength factor. Mean deposition constants of NO<sub>2</sub>, toluene and xylene were  $0.98 \pm 0.28$  kr<sup>-1</sup>,  $0.71 \pm 0.24$  and  $0.74 \pm 0.53$ , respectively. And source strengths of NO<sub>2</sub>, toluene and xylene were  $16.28 \pm 7.47$ ,  $31.25 \pm 38.45$  and  $23.45 \pm 19.67$  ppb/hr, respectively, in Table 2, 3 and 4.

**Table 2.** Estimated deposition constant and source strength of NO<sub>2</sub>.

	Deposition constant (K, hr <sup>-1</sup> )		Source strength (S, ppb/h)	
	M±S.D.	Range	M±S.D.	Range
Seoul (n= 8)	0.88±0.15	0.71~1.20	15.97±9.18	0.32~29.56
Asan (n= 9)	1.03±0.4	0.18~1.52	15.64±7.14	4.47~27.98
Daegu (n= 9)	1.01±0.18	0.85~1.36	17.38±6.89	8.38~27.16
Total	0.98±0.28	0.18~1.52	16.28±7.47	0.32~29.56

**Table 3.** Estimated deposition constant and source strength of toluene.

	Deposition constant (K, hr <sup>-1</sup> )		Source strength (S, ppb/h)	
	M±S.D.	Range	M±S.D.	Range
Seoul (n= 9)	0.63±0.21	0.35~0.87	30.32±21.56	15.98~75.28
Asan (n= 8)	0.76±0.34	0.37~1.01	21.65±22.54	14.68~95.68
Daegu (n= 9)	0.73±0.25	0.45~0.98	34.55±29.52	12.58~106.32
Total	0.71±0.24	0.35~1.01	31.25±38.45	12.58~106.32

**Table 4.** Estimated deposition constant and source strength of xylene.

	Deposition constant (K, hr <sup>-1</sup> )		Source strength (S, ppb/h)	
	M±S.D.	Range	M±S.D.	Range
Seoul (n= 9)	0.67±0.75	0.25~1.21	20.45±15.56	9.78~65.38
Asan (n= 8)	0.72±0.85	0.47~1.51	25.65±26.54	12.68~74.68
Daegu (n= 9)	0.76±0.59	0.35~1.56	26.35±31.5	18.98~86.62
Total	0.74±0.53	0.25~1.56	23.25±19.67	9.78~86.62

## Acknowledgement

This research was supported by Korea Institute of Environmental Science and Technology in 2004, Ministry of Environment, Korea.

## References

- Jones, A.P. (1999) "Indoor air quality and health", *Atmospheric Environment*, 33, 4535-4564.  
 Nazaroff, W.W. and Cass, G.R. (1986) "Mathematical modeling of chemically reactive pollutants in indoor air", *Environ. Sci. Technol.*, 20, 924-934.

- Ott, W., Switzer, P. and Robinson, J. (1996) "Particle concentrations inside a tavern before and after prohibition of smoking: evaluating the performance of an indoor air quality model", *Journal of the Air & Waste Management Association*, 46, 1120-1134.
- Spengler, J.D., Schwab, M., Ryan, P.B., Colome, S., Wilson, A.L., Billick, I.H. and Becker, E.J. (1994) "Personal exposure to nitrogen-dioxide in the Los-Angeles basin", *Journal of the Air & Waste Management Association*, 41, 39-47.
- Traynor, G.W., Apte, M.G., Dillworth, J.F., Hollowell, C.D. and Sterling, E.M. (1982) "The effects of ventilation on residential air pollution due to emissions from a gas-fired range", *Environment International*, 8, 447-452.
- Wade, W.A., Cote, W.A. and Yocom, J.E. (1975) "A study of indoor air quality", *Journal of the Air Pollution Control Association*, 25(9), 933-939.
- Yanagisawa, Y. and Nishmura, H. (1982) "A badge-type personal sampler for measurement of personal exposures to NO<sub>2</sub> and NO in ambient air", *Environment International*, 8, 235-242.